EUROPEAN COMMISSION

Area:
ENERGY AND TRANSPORT

# MUSEUMS
## ART MUSEUM OF KRISTINEHAMN
## NNE5-1999-20

ENERGIE

# Final Technical Report – Sweden 2000-01-01 – 2004-12-31

**Project Number:** NNE5/1999/20

Title of Project: Museums Energy Efficiency & Sustainability In Retrofitted & New Museum Buildings

Programme: ENERGIE

| | 1st Contractor | Assistant Contractor |
|---|---|---|
| **Name of the company**: | City of Kristinehamn | Christer Nordström Arkitektkontor AB |

| | Assistant Contractor |
|---|---|
| **Name of the company**: | WSP AB (renamed from AB Jacobson & Widmark) |

**Report prepared by:** Name of company: WSP AB (AB Jacobson & Widmark) and CNA (Christer Nordström Arkitektkontor AB)
Authors: Åke Blomsterberg and Christer Nordström

## Summary

The aim was to convert a larger former local district heating plant into an energy efficient art museum while preserving the character of the building. Before the renovation, the building had virtually no thermal insulation, poor windows and uncontrolled natural ventilation, thus being expensive to heat during the winter. New, economic and innovative methods for heating were necessary in order to use the building in wintertime. The following innovative features were implemented: a drastic increase of thermal insulation in the attic and in the basement, upgrading of windows, solar collectors for preheating of supply air, demand controlled hybrid ventilation, advanced climate control and BEMS, energy efficient lighting and improved daylighting.

The project has been realised according to the project description and so far without any major problems in operation.

The total investment cost (materials and installation) for the features improving the indoor climate and reducing the energy use is 604 770 Euro, of which 538 401 are eligible costs. The eligible costs related directly to reduced space heating and use of electricity are 355 862 Euros. There is however possibilities to reduce costs in the next project. The straight payback time is 43 years. The expected service life time of the improved mechanical and lighting system is longer than 25 years and for the building technology improvements 40 years.

The energy use for space heating was reduced by 50 % from 210 kWh/m$^2$,year to 107 kWh/m$^2$,year and could fairly easily be further reduced to the target 90 kWh/m$^2$,year. The use of electricity was increased due to additional equipment, otherwise the use electricity would have been lower than before 35 kWh/m$^2$,year and closer to the target 25 kWh/m$^2$,year, although the artificial lighting and ventilation were improved. The refurbished museum building is heated by district heating generated by a biomass (wooden fuel chips) heating plant. If the refurbished building had had an oil based heating system, then the reduction in $CO_2$ emissions would have been 48 tons/year for the obtained heating energy savings.

In Sweden many old building (mainly hospitals, factories and army buildings) are being converted into museums, offices etc., however seldom resulting in an energy efficient, healthy and sustainable building. This project has clearly demonstrated how these aims can be achieved.

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# 1. Project details

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| **Project Number:** NNE5/1999/20 |
| Title of Project: Museums Energy Efficiency & Sustainability In Retrofitted & New Museum Buildings |

Period covered: from 01/01/00 to 31/12/04

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| | 1st Contractor | Assistant Contractor |
|---|---|---|
| **Name of the company**: | City of Kristinehamn | Christer Nordström Arkitektkontor AB |
| **Contact person:** | Lars Nilsson | Christer Nordström |
| **Address:** *Country*<br>*Post-code, Town*<br>*Street* | Sweden<br>681 84 Kristinehamn<br>Järnvägsgatan 12 | Sweden<br>436 45 Askim<br>Åsstigen 14 |
| **Tel**:*(country) (area) number* | 0046 550 88000 | 0046 31 282864 |
| **Fax:***(country) (area) number* | 0046 550 88011 | 0046 31 681088 |
| **e-mail:** | lars.nilsson@kristinehamn | cna@cna.se |

| | Assistant Contractor |
|---|---|
| **Name of the company**: | WSP AB (AB Jacobson & Widmark) |
| **Contact person:** | Åke Blomsterberg |
| **Address:** *Country*<br>*Post-code, Town*<br>*Street* | Sweden<br>211 20 Malmö<br>Slagthuset |
| **Tel**:*(country) (area) number* | 0046 40 6996200 |
| **Fax:***(country) (area) number* | 0046 40 301463 |
| **e-mail:** | ake.blomsterberg@wsp.se |

**Report prepared by:** Name of company: WSP AB (AB Jacobson & Widmark) and CNA (Christer Nordström Arkitektkontor AB)

**Contact persons:**

Åke Blomsterberg
Address: Sweden, 211 20 Malmö, Slagthuset,
Tel: 0046 40 699 6331, Fax: 0046 40 301463
e-mail: ake.blomsterberg@wspgroup.se

Christer Nordström

Address: Åsstigen 14, SE 436 45 Askim,
Tel: 0046 31 28 28 64, Fax: 0046 31 68 10 88
e-mail: cna@cna.se

# 2. Aim and general description

## *2.1 Aim of the project*

The aim was to convert a larger former local district heating plant into an energy efficient art museum while preserving the character of the building. Before the renovation, the building had virtually no thermal insulation, poor windows and uncontrolled natural ventilation, thus being very cold and expensive to heat during the Scandinavian winter. New, economic and innovative methods for heating were necessary in order to use the building in wintertime. The following innovative features were to be implemented: a drastic increase of thermal insulation in the attic and in the basement, upgrading of windows, solar collectors for preheating of supply air, demand controlled hybrid ventilation, advanced climate control and BEMS, energy efficient lighting and improved daylighting.

The aim was based on a total energy optimisation to reduce the yearly use of district heating for the refurbished museum building for space and hot water heating by 70 %, and at the same time obtain a 30 % saving of total electricity and specifically a 40 % saving of electricity for lighting - compared with the situation before renovation i.e. a temporary exhibition building. The refurbished museum building is heated by district heating generated by a biomass (wooden fuel chips) heating plant. If the refurbished building had had an oil based heating system, then the reduction in $CO_2$ emissions would have been 75 % or 40 tons/year.

By introducing energy efficient, healthy and sustainable systems in museums the ambition was to set a good example in buildings which are visited by many persons i.e. a visible demonstrative effect. To the general public will also be shown that it can be done while still preserving the character of an existing building, but still giving the message that the building is an energy efficient, healthy and sustainable building.

In Sweden many old building (mainly hospitals, factories and army buildings) are being converted into museums, offices etc., however seldom resulting in an energy efficient, healthy and sustainable building. This project will demonstrate how these aims can be achieved.

## *2.2 Description of the site*

Kristinehamn is a city of 25 000 inhabitants, located at the coast of Sweden’s largest lake, Lake Vänern at latitude 58N. The city is among other things famous for hosting one of the largest statues of Pablo Picasso, overlooking the lake.

*Left: Map of south Sweden.  Right: The Picasso statue of Kristinehamn*

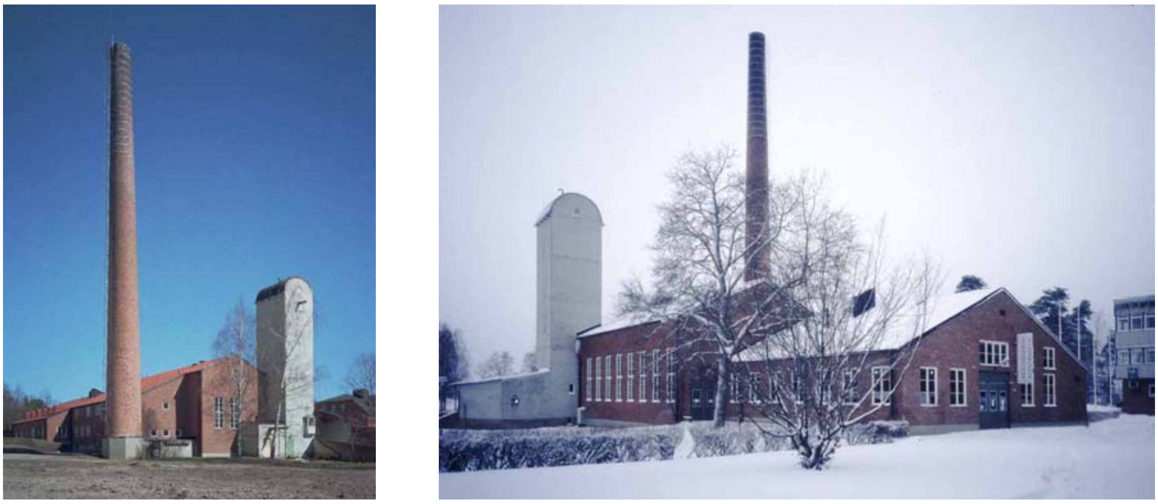
Marieberg, north of Kristinehamn was once a large mental hospital with more than one thousand employees. The magnificent 19th century brick buildings, located in a beautiful park landscape, are now standing empty as a result of a major reorganisation of the Swedish health care during the 1980ies. The area is currently being rebuilt and adapted for business operation and cultural activities.


*Left: The Marieberg area. Right: The heating plant before renovation and the former charcoal harbour*

In this area, the municipality of Kristinehamn, has converted a former coal fired heating plant into a museum for contemporary art. The reconstruction scheme was designed by Christer Nordström Arkitektkontor AB in cooperation with WSP Environmental with the focus on energy efficiency, the integration of renewable energy systems, optimised daylighting, environmental assessment and thermal comfort.

<u>The building</u>

The building was formerly used as heating plant for the very large hospital area. Charcoal was transported by sea to the hospitals own small harbour and then to a triangular coal yard and finally led to the 4 burners through a charcoal tower on the south side of the building. Hot water was distributed to the buildings within the hospital area through a system of culverts under ground. After the hospital area was connected to the city district heating system, the heating plant was closed.



*The former heating plant before renovation*

Before the renovation, the brick building had no thermal insulation besides a thin layer of mineral wool above some of the ceiling. The wooden frames of the windows were in quite good condition and could be renovated but the energy standard was poor due to air leakage and traditional double-glazed windows. Some of the rooms had old radiators, others had no heating system installed and the building was without ventilation system.

*The pictures show how the main exhibition hall and the library looked before the renovation*

The interior spaces were worn down and dirty after the previous use and the inner surfaces were in need of total renovation. The supporting building structure, on the other hand, was found to be solid. The exterior of the building with its brick facades, proportions, charcoal tower and high chimney, was very characteristic for the area and in sufficient condition to be preserved.

Before the refurbishment in this project the building was for a couple of years used for temporary exhibitions. To make this possible the building was cleared of the boiler installation etc. and some artificial lighting and electric heaters were added.

## 2.3 Description of the installation

After refurbishment the building incorporates three exhibition rooms – one large and two smaller rooms, and a café, museums shop, reception, creative workshop, library, conference room, office and staff spaces and storage rooms. The total floor area is 1 450 m$^2$ including 330 m$^2$ exhibition area. The museums is a museum of contemporary art. The building is mostly housing national and international temporary exhibitions including paintings, sculptures and installations.

Early in the project detailed performance specifications for energy use and indoor environment were developed (Annex 1, Blomsterberg 2001b)

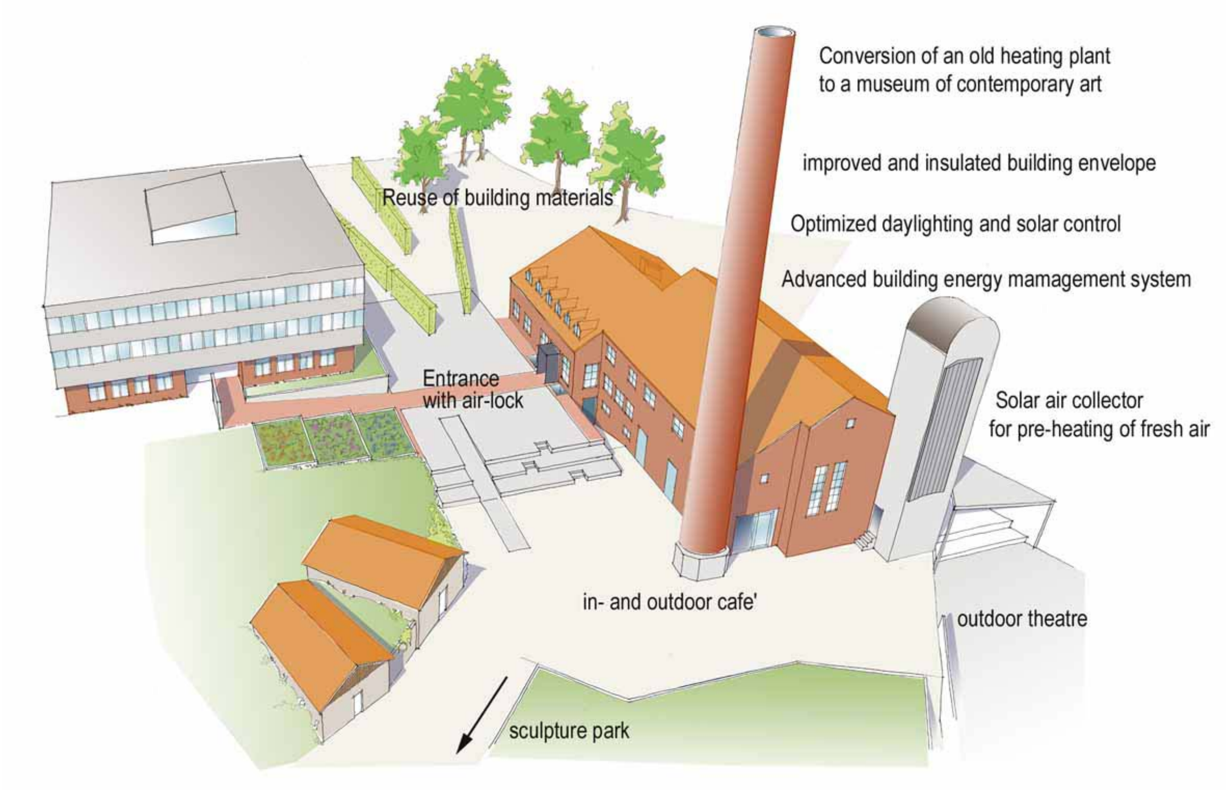



*Illustration: © Christer Nordström Arkitektkontor AB*

**<u>Optimised building envelope materials and components</u>**

Additional insulation has been added to the building envelope:

- Additional roof insulation of 400 mm mineral wool has been placed between the ceiling and the roof
- The exterior walls of the main exhibition halls have been internally insulated with 45 mm EPS.
- 70 mm of EPS insulation have been placed on the floors under the floor heating system.

Improved windows:

- Existing windows have been upgraded by replacing the inner pane of the old 2-pane windows with low-energy coated, heat reflecting panes
- New low energy windows with heat reflecting panes and have a U-value of less than 1.6 W/m$^2$K.


*Above: New windows are opened in the cafe*

An air lock has been installed in the main entrance in order to avoid cold draft.



*Left: Airlock in the main entrance. Right: Sorting of building waste*

Building materials have been carefully selected in order to minimise negative effects on the environment and people using the EPM method (Environmental Preference Method). This was done within the horizontal activity “Sustainable construction and materials”. New internal walls and intermediate floors are built of wood. Floors are made of massive wood, natural lime stone, ceramic tile or rubber. New windows are argon-filled LE-glazing with sealing cracks of EPDM. Insulation materials used are mineral wool and EPS. Natural paint has been used for exterior paintwork (walls). Interior paintworks are of water-based paint.

Environmental aspects have been taken into consideration when choosing materials for new water systems. Internal waste systems are made of PP (polypropylene). New WC-chairs have choice of water efficient flush. Water pipes are insulated with mineral wool. Gutter linings are made of rubber. Drains are tightened with rubber gaskets.

Building waste has been assorted in separate fractions, glass, paper/cardboard, wood, chemical waste and metals.

**Optimised electric and HVAC equipment integrating natural lighting**
The daylighting level is optimized (see below Passive solar control and daylighting optimisation).

Energy efficient lighting devices (HF neon tubes combined with presence detectors) have replaced the existing ones.

The specific use of electricity for ventilation was maximized to 1 kW/m³/s (see Annex I) by installing high efficiency fans and ensuring low pressure drops in the duct system. The overall use of electricity for ventilation was reduced by installing a demand control system and combining natural and mechanical driving forces in the ventilation system i.e. demand controlled hybrid ventilation in the exhibition rooms (see below Integration of renewable energy sources – Solar energy systems).

There is a back-up mechanical cooling system (see Integrated load management for heating, cooling and electricity consumption) . Cooling is mainly achieved by night cooling.

**Integrated load management for heating, cooling and electricity consumption**
An advanced building energy management system (BEMS) including a smart control system for heating, cooling and ventilation has been installed. The BEMS controls and monitors the operation of the heating, cooling, humidification, dehumidification, ventilation and energy use of the building. For indoor climate reasons the building is divided into two different zone: exhibition rooms and non-exhibition rooms. The BEMS is also used for detailed monitoring of the indoor climate and energy use.

The BEMS is a computerized building automation system. Data is stored and can be retrieved from a workstation in the building, which can be accessed via Internet. All the monitored data and the flow diagrams with instantaneous measured values, set points for temperatures, relative humidity, carbon dioxide, time schedules etc. can be accessed and downloaded via Internet. A user with the right qualification can adjust the set points via Internet.

There are basically two different operational modes:
1. Stringent indoor climate requirements, when the indoor temperature and humidity has to be controlled within a narrow band
2. Normal indoor climate requirements, when the only need is to maintain the temperature above a certain level

An example of the rare occasion where case 1 applies was during the first exhibition, the Picasso exhibition. The set point for mechanical cooling was 21 °C. The set point for preheating of the supply air is 16 °C, unless cooling is required. The set points for humidification was a relative humidity of 43 % and for dehumidification 47 %. Night cooling with ventilation is used to cool the building to 20 °C. For indoor air quality the ventilation is demand controlled using the $CO_2$ level, if the level exceeds 800 ppm the ventilation rate is increased i.e. the amount of outdoor air is increased and the amount of return air is decreased..

For normal indoor climate requirements, which is the case most of the time, there are no mechanical cooling, no humidification and no dehumidification. Night cooling with ventilation is used if in the evening the indoor temperature is higher than 23 °C. The day and night ventilation rates are controlled at different levels by a time schedule. The night ventilation rate is typically half of the day rate. The demand control during office hours is the same as above.

For both cases the control system will determine, when heating is required, whether it makes sense of not to bring the outdoor air through the solar collector or not, for preheating purposes.

Air handling unit for the non-exhibition rooms
The indoor temperature is controlled, the set point for cooling is 23 °C. As there is no mechanical cooling the last requirement can not always be fulfilled. Some cooling is done by the rotary heat exchanger and night cooling is also used. The supply air is preheated to 16 °C, unless it is too warm inside. There are two different fan speeds, a high one for office hours and a low one for nights, controlled by a time schedule.

Heating system
There are basically two different operational modes:

1. Stringent indoor climate requirements, when the indoor temperature and humidity has to be controlled within a narrow band
3. Normal indoor climate requirements, when the only need is to maintain the temperature above a certain level

An example of where case 1 applies was for the exhibition rooms during the first exhibition, the Picasso exhibition. The set point for heating was then 19 °C. For normal indoor climate requirements the set point for heating can be 21 °C.

For the non-exhibition rooms the control of the heating system, radiators, is similar. However, the radiators are equipped with thermostatic valves.

**Integration of renewable energy sources – Solar energy systems**

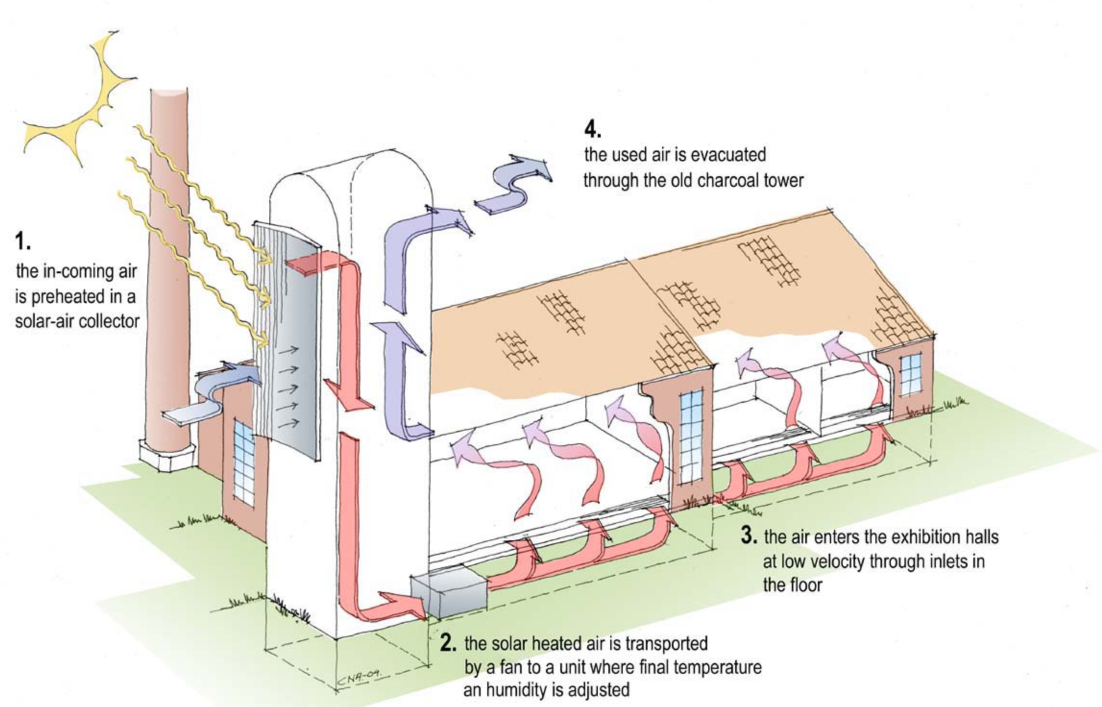



*Illustration: © Christer Nordström Arkitektkontor AB*

The outdoor air for the exhibition rooms is preheated by a air solar collector placed on the south facade of old coal tower. The solar collector is un-glazed and of a so-called flowing-through design where the fresh air passes through small holes in the absorber plate. This gives high heat transfer and efficiency. The solar heated air is supplied with a $CO_2$ controlled (controlling the $CO_2$ level inside) fan to the exhibition rooms through inlets in the floor and are finally evacuated with natural ventilation through the old coal tower. This means that the exhibition rooms have a system for demand controlled hybrid ventilation. Other spaces have been equipped with mechanical ventilation with modern and efficient heat recovery (rotary heat exchanger).

*Left: Solar collector under construction. Middle and Right: Solar collector after installation*

**<u>Passive solar control and daylighting optimisation</u>**

To be able to utilise as much daylight as possible and at the same time protect the objects of art against UV-radiation daylighting must be carefully considered and designed. In order find the right solutions and to optimize the daylight and acoustic situation, the design team was assisted by prof. Mike Wilson of London Metropolitan University.

In order to create a flexible system, the windows of the exhibition halls were equipped with a double blind system. With a remote control for the blinds, the daylight can be varied within the range from full daylight inlet to total darkness.

The inner glass panes of the windows have been replace by new energy reflecting panes with reduction of UV-light.

*Left: the daylight/shadingt blind system in half daylight mode. Right: The daylight blind in dark mode*

**Acoustics**
The acoustic situation before the renovation was unacceptable and Prof. Wilson monitored reverberation times exceeding 5 seconds. After installation of a suspended ceiling with acoustic panels, the acoustic situation is now good.

**Security**
The museum building is designed for maximum security and has achieved the highest possible security ranking. This means that the Museum is allowed to host extremely valuable national and international exhibitions, such as the inauguration exhibition "The Public Art of Pablo Picasso". Detailed security instructions and regulations are made for the building and the activities. Following these instructions, it is not allowed to distribute drawings and descriptions showing in detail the building and the installations to the public.

## *2.4 Description of the performance monitoring and measuring system*

The monitoring period will begin with one time tests to discover if the installed heating and ventilation system is functioning as designed and to determine certain values (Blomsterberg 2002). To characterize the indoor climate the thermal comfort will be monitored during the one-time tests. The above measurements will be complemented with a standard indoor climate questionnaire to find out how the users perceive the indoor climate, heating and ventilation system and how the building is used (e. g. occupancy profiles). This will be done when the museum has been used for one year.

The actual monitoring phase will include continuous measurements of outdoor environment, indoor environment, energy use and system operation. The actual monitoring phase will last at least 12 months. The monitoring system will be integrated with the building energy management system (BEMS). All the measuring points below are recorded and stored as hourly values by the building automation system (BEMS).

AS1 = appliance cupboard (apparatskåp) for LA1 air handling unit for the non-exhibition rooms
AS2 = appliance cupboard (apparatskåp) for TA2 air handling unit for the exhibition rooms

| **Quantity** | **Location** |
|---|---|
| **Outdoor environment** | |
| Solar radiation (global on horizontal plane) | SO51-AS2, on top the charcoal tower |
| Wind velocity and direction | RV51-AS2 and RV52-AS2, on top of the charcoal tower |
| Outdoor temperature | GT51-AS1 on the north façade, 3 m above ground |
| **Indoor environment for representative rooms** | |
| Indoor temperature | Main exhibition hall, inner corner:<br>- GT11-AS2, 1.1 m above floor<br>- GT13-AS2, 1.8 m above floor<br>- GT14-AS2, 0.1 m above floor<br>Small exhibition room, inner wall:<br>- GT15-AS2, 1.6 m above floor<br>Graphical room, inner wall:<br>- GT12-AS2, 1.6 m above floor<br>Library, inner wall:<br>- GT12-AS1, 1.6 m above floor<br>Café (kitchen), inner wall:<br>- GT11-AS1, 1.6 m above floor<br>Creative workshop, inner wall:<br>- GT13-AS1, 1.1 m above floor<br>Shop, inner wall:<br>- GT14-AS1, 1.1 m above floor<br>Basement, room next to room with TA2:<br>- GT11-AS3, wall between spare room and district heating central |
| Relative humidity | Main exhibition hall, inner corner:<br>- GH11-AS2, 1.1 m above floor (next to GT11)<br>Graphical room, inner wall:<br>- GH12-AS2, 1.1 m above floor (next to GT12) |
| Carbondioxide | Main exhibition hall, inner corner:<br>- GX11-AS2, 1.1 m above floor (next to GT11) |
| **Energy use** | |
| Space heating | VMM1, District heating |
| Space cooling (if mechanical cooling) | Separate electricity meter |
| Humidifier | Separate electricity meter |
| Hot water | |
| Electricity for ventilation | Exhibition rooms (TA2):<br>- M1-AS2, Air handling unit excl. cooling and humidification |
| Electricity for ventilation | Non-exhibition rooms (LA1):<br>- M1-AS1, Air handling unit |
| Electricity for lighting | Total – above |
| Total electricity | |
| Contribution from solar collector | GT51-AS1, outdoor temperature<br>GT51-AS2, air temperature after solar collector |

| | |
|---|---|
| Efficiency of heat exchanger | Non-exhibition rooms (LA1):<br>- GT31-AS1, exhaust air temperature<br>- GT32-AS1, extract air temperature<br>- GT51-AS1, outdoor temperature<br>- GT22-AS1, supply air temperature before rotary heat exchanger |
| **System operation** | |
| Window opening | |
| Operating times e. g. different fan speeds | Start/stop times, according to schedule |
| Air velocity and direction in passive stack | GF31-AS2, return duct air flow metering |
| System temperatures | Exhibition rooms (TA2):<br>GT23-AS2, supply air temperature before air handling unit<br>GT81-AS2, heating coil in plant room (freezing guard)<br>GT22-AS2, supply air temperature after heating/cooling and before fan<br>GT21-AS2, supply air temperature after fan<br>GT24-AS2, supply air temperature after humidifier<br>GT32-AS2, exhaust air temperature behind exhaust air terminal device<br>GT31-AS2, exhaust air temperature at top of exhaust duct<br>GT72-AS1, heating coil forward<br>GT71-AS1, heating coil return |
| Floor heating | VS61-GT71, forward temperature<br>VS61-GT91, return temperature |
| Radiator heating | VS41-GT71, forward temperature<br>VS41-GT91, return temperature |
| Passive stack damper | ST53-AS2, top of passive stack, min 20 %, |
| Solar collector damper | ST51-AS2, top of passive stack, |
| Outdoor air north damper | ST52-AS2, top of passive stack, min 20 %, |
| Return air damper | ST54-AS2, return air duct, |
| Pressure drop | Exhibition rooms (TA2):<br>GF21-AS2, across supply fan |
| System temperatures | Exhibition rooms (LA1):<br>GT81-AS1, heating coil in plant room (freezing guard)<br>GT72-AS1, heating coil forward temperature<br>GT71-AS1, heating coil return temperature<br>GT21-AS1, after supply fan |
| Frequency | Exhibition rooms (TA2):<br>fan in fan room |
| Pressure | Non-exhibition rooms (LA1):<br>GP21-AS1, supply duct after supply fan in plant room<br>GP31-AS1, exhaust duct before components<br>GF21-AS1, across supply fan<br>GF31-AS1, across exhaust fan |
| Frequency | Non-exhibition rooms (LA1):<br>fans in fan room |

The one time tests will be evaluated by a comparison with the project specific performance specifications (Annex I, Blomsterberg 2001b).

The continuous long-term measurements will be compared with the project specific performance specifications and the original energy calculations. The original energy simulations will be adjusted to the measured boundary conditions. Differences in occupancy compared with the original assumptions during design will be taken into account. The simulations are also used to further evaluate and analyse the measurements.

# 3. Operation and results

## *3.1 Operating history*

The building was inaugurated on the 26th of April 2003 and has been in operation since then. The museum is normally open to the public Tuesday – Sunday, between 12 – 16 o'clock. The monitoring was carried out from May 2003 to October 2004.

## *3.2 Performance*

Before and during design simulations were carried out. The aim was to determine if the proposed energy, thermal comfort and indoor air quality performance requirements could be fulfilled in a refurbishment incorporating a system for demand controlled hybrid ventilation. The energy use if the building was not refurbished was also simulated i.e. for the case with natural ventilation, a simple heating system, traditional artificial lighting and normal museum occupancy. The energy use was predicted using a dynamic energy simulation program, IDA ICE.

Table 4.1 Simulated energy use before and after refurbishment, and measured after refurbishment. The energy use for heating is normalized to the same reference climate and occupancy profile.

| | Before retrofit | | Performance specifications | | Measured after retrofit | | Energy savings |
|---|---|---|---|---|---|---|---|
| | $kWh/m^2y$ | MWh/y | $kWh/m^2y$ | MWh/y | $kWh/m^2y$ | MWh/y | % |
| Heating | 210 | 305 | 90 | 131 | 107 | 155 | 49 |
| Electricity | 35 | 51 | 25 | 36 | 42 | 61 | -20 |
| Total | 245 | 355 | 115 | 167 | 149 | 216 | 39 |

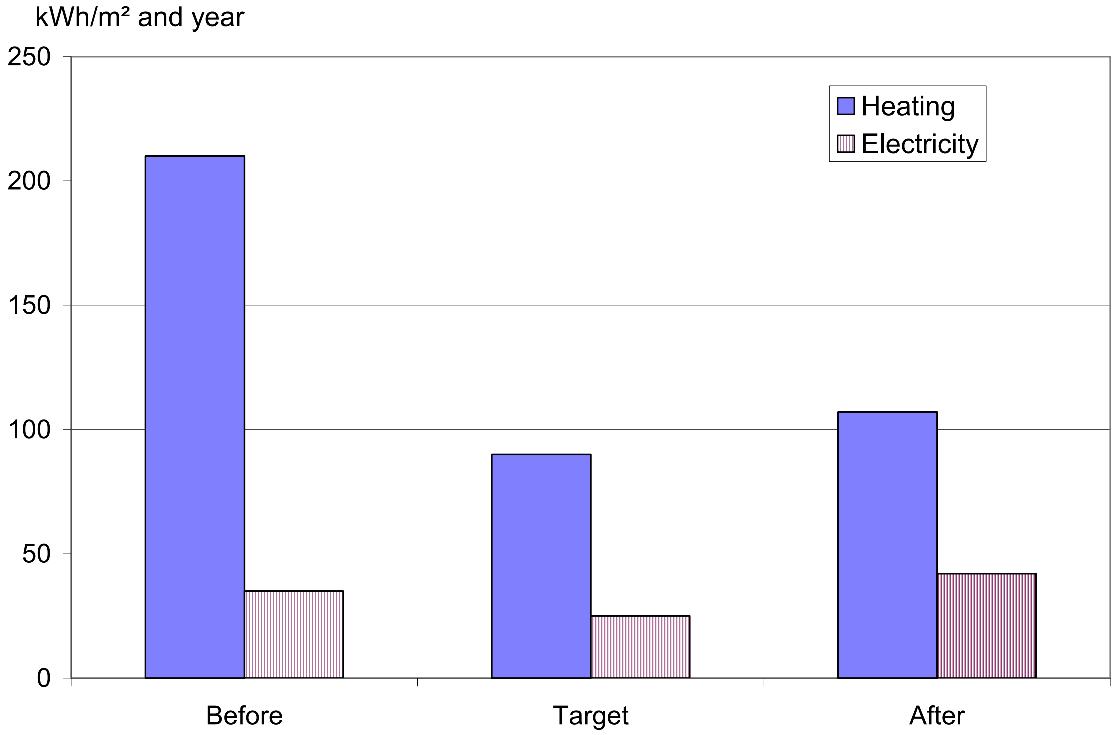



Figure 4.1 Energy use for heating (district heating) and use of electricity, before and after retrofit, and the target according the performance specifications.

Air flow simulations for the hybrid ventilation system were carried out as support for the dimensioning.

The simulations showed that the proposed refurbishment was feasible.

The performance monitoring included three visits to the building in order to carry out one-time tests. During the first visit (August 2003), the air flows in the hybrid ventilation system of the exhibition halls were examined using tracer gas and pressure measurements. During normal operation 80 % of the ventilating air is supposed to be recirculated according to design i.e. 20 % outdoor air and 20 % extract air. The total air flow agrees fairly well with what the HVAC contractor claims and the design value (see table 4.2). If the outdoor air comes directly from the outside through the supply duct, then 74 % will be recirculated. If the outdoor air comes through the solar collector, then the total air flow will be 10 % lower and 79 % will be recirculated, due to a higher pressure drop across the solar collector (Blomsterberg 2005). The amount of extract air through the passive stack (coal tower) will of course increase, when it is cold outside.

Table 4.2 Total air flow in the demand controlled hybrid ventilation system serving the exhibition rooms.

| | Total air flow, l/s | Accuracy |
|---|---|---|
| Tracer gas measurement | 987 | ± 49 |
| According to HVAC contractor | 1030 | |
| Design | 1047 | |

Shortly after commissioning, it was also discovered that the fans serving the non-exhibition rooms were running at full speed 24 hours a day. This was readjusted to full speed between 12 and 18 o'clock, when the building is occupied, and the remaining time at half speed (50 % of the normal air flow). This saves energy use for space heating and fan electricity.

The specific fan power for the fans were determined for normal operation. The value for the supply fan to the exhibition rooms was 1.2 kW/(m$^3$/s) and for the air handling unit serving the non-exhibition rooms 2.2 kW/(m$^3$/s). The requirement was 1 kW/(m$^3$/s).

The thermal comfort measurements carried out in November of 2003 showed that the requirements were fulfilled in the exhibition rooms, but not in the café. An occupants survey gave the same result. As a result the heating system was adjusted.

The energy use and indoor climate was monitored for 1.5 years. The normalized actual energy use is for heating 107 kWh/(m$^2$ of floor area and year) and electricity 42 kWh/(m$^2$ of floor area and year). The energy gain from the solar collector has been measured to be approximately 7 kWh/(m$^2$ of floor area and year) (10 MWh/year), which is close to the original prediction. Temperatures in the exhibition halls varied between 20 – 25 ˚C in summertime and 19 – 20 ˚C in wintertime during the period October 2003 – September 2004 (see figure 4.2). However, for the very strict indoor climate requirement (operative temperature: 18 – 22 °C, relative humidity: 45 – 60 %, max 5 % variation/day) for sensitive exhibits the back-up cooling, humidifying and dehumidifying unit is needed. As to the indoor air quality the $CO_2$ level was never above 800 ppm within the occupied zone of the exhibition rooms.

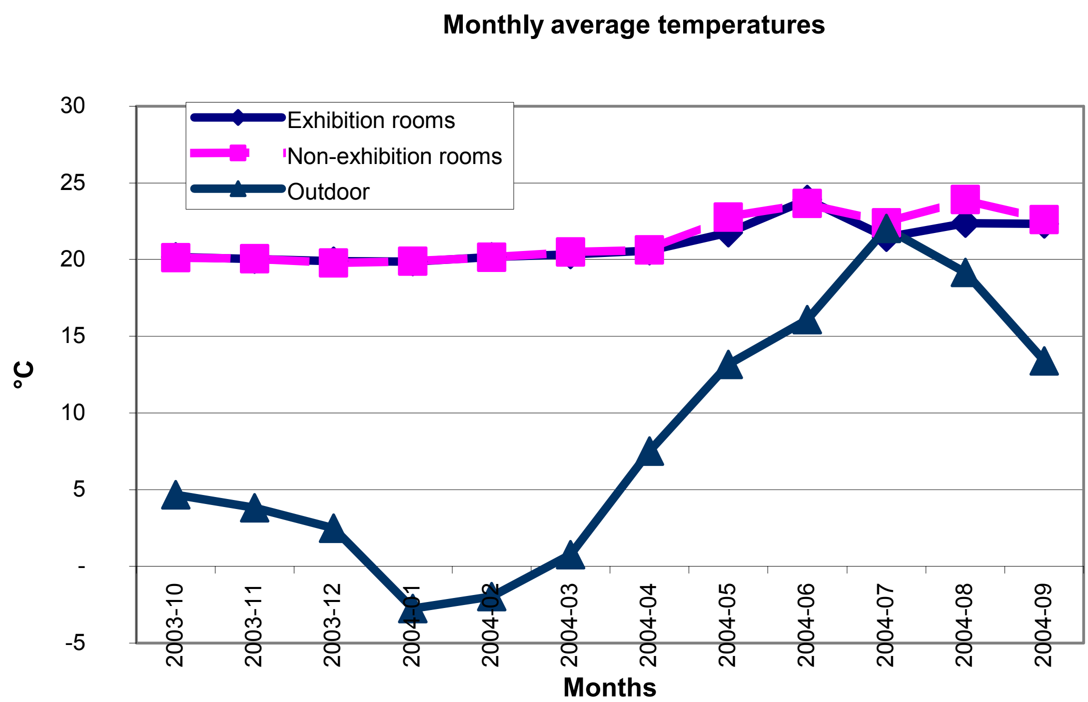



Figure 4.2 Measured monthly average temperatures, October 2003 – September 2004. Remark during part of July and August the cooling unit for the exhibition rooms was turned on.

Further energy savings are clearly possible. The following measures then have to be carried out:

1. The damper in the charcoal tower (passive stack), ventilating the exhibition rooms, has to be gradually closed as a function of the outdoor temperature i.e. at very low outdoor temperatures be almost closed. This way the excess ventilation during winter, due to excess natural ventilation, can be avoided.
2. The airtightness of the building has to be further improved.
3. All windows have to be changed to low energy windows.
4. The thermal bridges have to be further reduced.

Measure 1 is very cost effective. Measures 2, 3 and 4 are not cost effective.

If these additional energy saving measures are carried out, then the target energy use for heating of 90 kWh/m$^2$,year can be met. The estimated energy use before refurbishment was 210 kWh/m$^2$,year for heating and 35 kWh/m$^2$, year for electricity. The actual use of electricity is higher than the target of 25 kWh/(m$^2$ of floor area and year) because of additional equipment, which was added:

- for the café kitchen.
- computers etc.

By introducing energy efficient, healthy and sustainable systems in museums we are setting a good example in buildings which are visited by many persons i.e. a visible demonstrative effect. To the general public is and will also be shown that it can be done while still preserving the character of an existing building, but still giving the message that the building is an energy efficient, healthy and sustainable building.

The refurbished art museum of Kristinehamn fulfils the project specific indoor climate requirements i.e. requirements of a modern art museum, which was not the case before refurbishment. For the very strict indoor climate requirement (operative temperature: 18 – 22 °C, relative humidity: 45 – 60 %, max 5 % variation/day) for sensitive exhibits the back-up cooling, humidifying and dehumidifying unit has to be used. The project specific requirements on energy use can be fulfilled. The energy use as it is today after refurbishment is lower than for two other new museums (built 1980 and 1982) and typical modern office buildings (see figure 4.3).

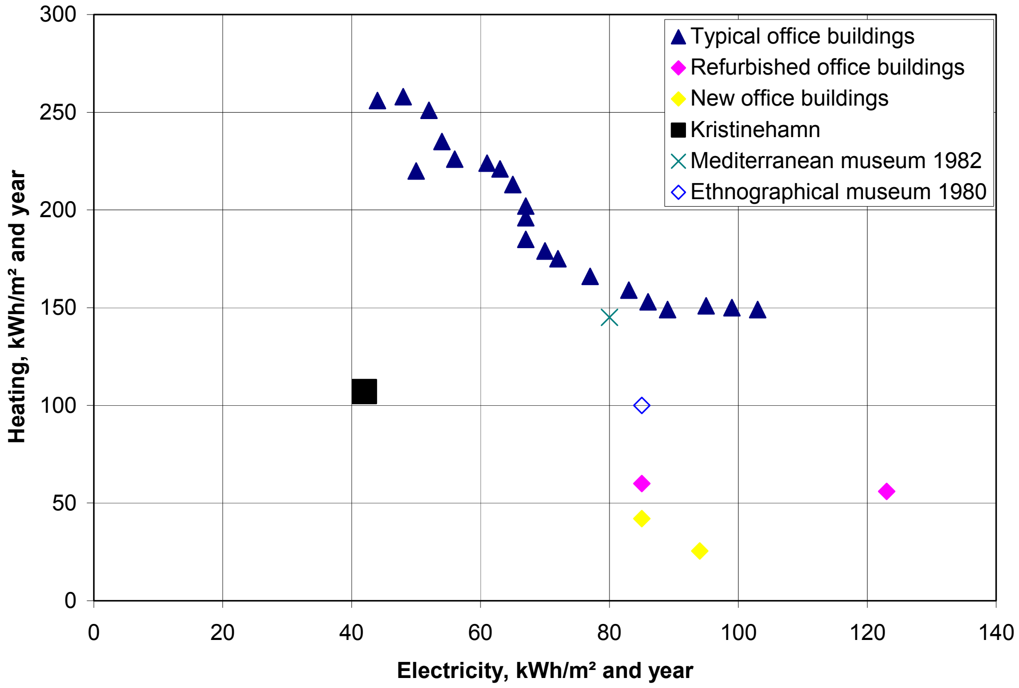



Figure 4.3 Energy use for heating vs. use of electricity for office and museums buildings.

Most the energy measures are profitable only if they are carried out at the same time as a refurbishment due to wear and tear or change of use. They are also likely to be more profitable for a bigger building than the art museum of Kristinehamn.

### *3.3 Success of the project*

The project can be considered to be a success. The project has been realised according to the project description and so far without any major problems in operation.

In Sweden many old buildings (mainly hospitals, factories and army buildings) are being converted into museums, offices etc., however seldom resulting in an energy efficient, healthy and sustainable building. This project has clearly demonstrated how these aims can be achieved.

### *3.4 Operating costs*

The operating costs comprise electricity and district heat. The yearly energy savings is 139 MWh. However the increased use of electricity should not be included, as the increase is mostly due to additional equipment, which did not exist in the building before retrofit. The yearly energy savings is thus 149 MWh. The supervision and maintenance is expected to be the same as before i.e. no savings in maintenance costs.

| | Before retrofit | | Measured after retrofit | | Energy savings | |
|---|---|---|---|---|---|---|
| | MWh/y | Euro | MWh/y | Euro | MWh/y | Euro |
| Heating | 305 | 16 917 | 155 | 8 619 | 149 | 8 297 |
| Electricity | 51 | 5 075 | 61 | 6 090 | -10 | -1 015 |
| Total | 355 | 21 992 | 216 | 14 709 | 139 | 7 282 |

### *3.5 Future of the installation*

The city of Kristinehamn is responsible for the operation of the building and will be so in the future. The technical management is taken care of by a subcontractor.

### *3.6 Economic viability*

The total investment cost (materials and installation) for the features improving the indoor climate and reducing the energy use is 604 770 Euro, of which 538 401 are eligible costs. The eligible costs related directly to reduced space heating and use of electricity are 355 862, excluded is 30 % of the eligible costs for heating and ventilation system incl. solar and BEMS, 100 % of the costs for climate control and shading devices.

| Measure | Investment costs, SEK | Euro | Eligible costs, SEK | Euro |
|---|---|---|---|---|
| Environmental clearance | 1 000 000 | 109 220 | 0 | 0 |
| Painting of the interior, new floor covering, safety for insurance, fire safety | 8 151 463 | 890 306 | 0 | 0 |
| Additional thermal insulation, attic | 275 329 | 30 072 | 247 795 | 27 064 |
| Heating and ventilation system incl. solar and BEMS | 3 571 630 | 390 095 | 3 035 885 | 331 581 |
| Energy efficient windows | 90 000 | 9 830 | 90 000 | 9 830 |
| Climate control (temp, humidity etc.) | 448 025 | 48 933 | 448 025 | 48 933 |
| Energy efficient ligthing | 102 000 | 11 140 | 102 000 | 11 140 |
| Shading device + daylight control | 312 500 | 34 131 | 312 500 | 34 131 |
| Improved daylighting | 293 800 | 32 089 | 293 800 | 32 089 |
| Add thermal insulation, basement | 443 872 | 48 480 | 399 484 | 43 632 |
| Energy saving measures | 5 537 156 | 604 770 | 3 258 199 | 355 862 |
| Total | 14 688 619 | 1 604 297 | 4 929 489 | 538 401 |

The <u>commercial version of the payback</u>, is given by the following expression

$$P_{comm} = \frac{I_{comm}}{E-M_{comm}} = 355\ 862 / (8\ 297 - 0) = 43 \text{ years}$$

where:

$I_{comm}$ is the difference between the procurement costs of a conventional technology and the innovative technology respectively (without taking into account with interests, depreciation, etc.).

E is the difference between the annual costs of the energy consumption and/or production between the conventional and the innovative (improved) technologies.

$M_{comm}$ is the difference between the annual operation costs (as defined under § 4.4) of the conventional and the improved/innovative technology applied in this commercialised installation/device.

The expected service life time of heating and ventilation system incl. solar and BEMS, climate control, energy efficient lighting is longer than 25 years. The expected service life time of additional thermal insulation, energy efficient window, shading devices and improved daylighting is longer than 40 years. There is however possibilities to reduce costs.

### *3.7 Environmental impact*

The refurbished museum building is heated by district heating generated by a biomass (wooden fuel chips) heating plant. If the refurbished building had had an oil based heating system, then the reduction in $CO_2$ emissions would have been 48 tons/year for the obtained heating energy savings.

Building materials have been carefully selected in order to minimise negative effects on the environment and people using the EPM method (Environmental Preference Method). This was done within the horizontal activity “Sustainable construction and materials”.

New internal walls and intermediate floors are built of wood. Floors are made of massive wood, natural lime stone, ceramic tile or rubber. New windows are argon-filled LE-glazing with sealing cracks of EPDM. Insulation materials used are mineral wool and EPS. Natural paint has been used for exterior paintwork (walls). Interior paintworks are of water-based paint.

Environmental aspects have been taken into consideration when choosing materials for new water systems. Internal waste systems are made of PP (polypropylene). New WC-chairs have choice of water efficient flush. Waterpipes are insulated with mineral wool. Gutterlinings are made of rubber. Drains are tightened with rubber gaskets.

Building waste has been assorted in some separate fractions, glass, paper/cardboard, wood, chemical waste and metals.

## 4. Publicity, commercialisation and other developments

### *4.1 Publicity and publications*

The project has received extensive publicity in Sweden, as well as in international contexts.
- Stockholm (Building research council) at 2 occasions
- Netherlands (Delft university and Rotterdam) 2003, 4 presentations
- Kristinehamn – public presentations
- Lyon 2002, international conference EPICAIVC2002
- Hydra, Greece, Museums conference 2003

The project was presented on national television on the 14th of December 2002.

The opening exhibition the public works of Picasso, began on the 26th of April 2003 and lasted for three months, presenting international sculpture works of the artist. 12 000 persons saw the exhibition. The exhibition was inaugurated by the Swedish minister of culture.

The project has been presented in Projekt och affärer in 2001, WSP customer magazine with a circulation of 18 000. The magazine is also published in Swedish and English on the web site of WSP, which has offices in Great Britain, Sweden, South Africa, Hong Kong, U.S.A. etc.

The project was presented at a workshop of an international conference EPICAIVC2002, 2002 in Lyon, France

CADDET info newsletter "Info Point", November 2003

The following brochures have been printed:
- Brochure for the Kristinehamn Museum of Contemparary Art, (English) 2001
- Brochures for the Swedish National Building Research Council, in English and Swedish 2003, 2004
- Brochure as a part of the Museums handbook
- 16 page brochure in English and Swedish printed in 500 copies 2004.

### *4.2 Outlook*

By introducing energy efficient, healthy and sustainable systems in museums we are setting a good example in buildings which are visited by many persons i.e. a visible demonstrative effect. To the general public is and will also be shown that it can be done while still preserving the character of an existing building, but still giving the message that the building is an energy efficient, healthy and sustainable building.

In Sweden many old buildings (mainly hospitals, factories and army buildings) are being converted into museums, offices etc., however seldom resulting in an energy efficient, healthy and sustainable building. The step from being interested to making a decision to realise innovative measures is often long for public buildings due to political as well as financial reasons. However there is new government program for retrofitting public buildings coming up.

### *4.3 Commercialisation*

All of the products used in the refurbishment of the museum in Kristinehamn are available on the market. Most the energy measures are, however, profitable only if they are carried out at the same time as a refurbishment due to wear and tear or change of use. They are also likely to be more profitable for a bigger building than the art museum of Kristinehamn.

## 5. Lessons learned/conclusions

The Kristinehamn project has caught a lot of interest from journalists and the users of the building are so far satisfied with their new environment.

This refurbishment project combines traditional and innovative energy saving measures. It proves that the conversion of old building (mainly hospitals, factories and army buildings) into museums, offices etc., can be done in an energy efficient, healthy and sustainable way.

The project had not been possible without the genuine interest from the building owner to implement innovative measures. The possibility to receive financial support from EC has been an important incentive.

Furthermore, the use of experienced consultants and rather detailed analyses regarding possible energy savings and especially combinations of these are important prerequisites in order to arrive at good results. The performance monitoring has further improved the results, by discovering simple improvements which could be carried out and by giving a good tool for operations monitoring, the Internet accessible BEMS. Even the staff of the museum has made use of this feature.

It is very important to fine tune and optimise the operation of a building according to the actual activity taking place during the first year of operation. A low energy use and good indoor climate can be obtained.

All measures have in principle met the expectations, the projected cost are exceeded with 20 % and the actual energy savings are in reasonable agreement with the expectations. The pay-back of the energy saving measures is rather long. It is, however, clearly possible to reduce cost. This was first time this combination of measures was implemented and if the project was bigger the costs would also be reduced.

## 6. References

### *Referred to in this report*

Blomsterberg, Å., 2001. Intermediate Technical Report Sweden 2000-01-01 – 2000-12-31. WSP Environmental, Malmö.

Blomsterberg, Å., 2001b. Art museum of Kristinehamn, performance specifications. 2001-10-02 rev. 2002-06-22, WSP Environmental, Malmö.

Blomsterberg, Å, 2002. Kristinehamn monitoring plan. WSP Environmental, Malmö.

Blomsterberg, Å., 2002b. Intermediate Technical Report Sweden 2001-01-01 – 2001-12-31. WSP Environmental, Malmö.

Blomsterberg, Å., 2003. Kristinehamn measuring points – Continuous measurements. WSP Environmental, Malmö.

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Blomsterberg, Å., 2004. Intermediate Technical Report Sweden 2003-01-01 – 2003-12-31. WSP Environmental, Malmö

Blomsterberg, Å. and Larsson, T., 2005. Monitoring of the art museum in Kristinehamn. WSP Environmental, Malmö.

Holmberg, S., 2000. Kristinehamns konstmuseum – Panncentralen – Inventering inför ombyggnad. WSP Environmental, Malmö.

### *Deliverables*

| Deliverable No | Deliverable title | Author and year published |
|---|---|---|
| 1 | State of the art report for Sweden | - A. Nordström, S. Holmberg, and Å. Blomsterberg. 2002 |
| 2 | Architectural design package including plans, relevant details and features with specifications | - C. Nordström, CNA, Complete set of drawings 2002-03-28 completed 2002-10-22<br>- B. Calheim, CA, Building description for tendering 2002-03-28<br>- C Nordstrom, CNA, Quaility Control Plan with completed checklist 2003-04-16<br>- Blomsterberg 2001 (intermediate technical report)<br>Architectural and building drawings, details and specifications are regarded as confidential information (not public) according to museum security regulations |
| 3a | M/E design package including plans, relevant details and features with specifications | - Blomsterberg 2001,<br>- Blomsterberg 2002b<br>- R. Larsson, WSP, Air handling system (drawings and technical description), 2002-03-28 (in Swedish)<br>- R. Larsson, WSP, Heating and cooling system (drawings and technical description), 2002-03-28 (in Swedish)<br>- R. Larsson, WSP, BEMS (drawings and technical description), 2002-08-12 (in Swedish)<br>M/E drawings and specifications are regarded as confidential information (not public) according to museum security regulations |
| 3b | Lighting design package including plans, relevant details and features with specifications | - T. Strandh, WSP, Electrical and telecommunications (drawing and technical description), 2002-03-28 (in Swedish) |
| 3c | Acoustic design report | - M. Wilson, London Metropolitan University, 2001 |
| 3d | Energy simulations report | - F. Övegard and Å. Blomsterberg, WSP, 2002 |
| 3e | Rating report on simulated buildings | - F. Övegard and Å. Blomsterberg, WSP, 2002 |
| 4a | Completed building with all installations | - Construction including installations completed in 2003. The building was inaugurated in april 2003 |

| | | |
|---|---|---|
| 4b | Building and features documentation | - The building is documented in drawings, descriptions and specifications. Referring to museum security regulations, detailed information on building and installations is regarded as confidential and access and publishing requires approval by authorized person in charge of the museum security. |
| 5 | Commissioning report | - Air handling unit and air flow protocols, Bravida, 2003-04-04 (in Swedish) |
| 6a | Monitoring plan with systems descriptions | - Kristinehamn monitoring plan, Å. Blomsterberg, WSP Environmental, 2002<br>- Kristinehamn measuring points – Continuous measurements, Å. Blomsterberg, 2003 |
| 6b | Occupants survey | - Monitoring of the art museum in Kristinehamn, Å. Blomsterberg and T. Larsson, WSP Environmental, 2005 |
| 7a | Final report with monitoring results, analysis and evaluation | - Monitoring of the art museum in Kristinehamn, Å. Blomsterberg and T. Larsson, WSP Environmental, 2005 |
| 7b | Rating report on executed buildings | - Monitoring of the art museum in Kristinehamn, Å. Blomsterberg and T. Larsson, WSP Environmental, 2005 |
| 8a | Newsletters | - C Nordström, contribution to all MUSEUMS newsletters |
| 8b | Brochures | - C Nordstrom and Kristinehamn Museum of Contemparary Art, Brochure presenting the project (English) 2001<br>- C Nordstrom and The Swedish National Building Research Council, Brocures of the project in English and Swedish 2003, 2004<br>- C Nordstrom, Project Brochure as a part of the Museums handbook<br>- C Nordstrom, Å Blomsterberg, 16 page brochure in English and Swedish printed in 500 copies 2004. |
| 8c | Web-site | - Contribution to the MUSEUMS website<br>- Project presentation on the CNA website (in Swedish) |
| 8d | Articles, presentations | - Å. Blomsterberg, Projekt och affärer, WSP customer magazine, 2002<br>- Å. Blomsterberg, EPICAIVC2002 workshop, 2002 in Lyon, France<br>- CADDET info newsletter "Info Point", November 2003<br>- Museum ingaguration in april 2003 by the Swedish Culture Minister.<br>- Interview with the museum director in national television 2003<br>- C Nordstrom, 2 presentation in Stockholm (Building research council)<br>- C Nordstrom, 4 presentations in the Netherlands (Delft university and Rotterdam) 2003<br>- C Nordstrom, Public presentation in Kristinehamn 2003<br>- C Nordstrom, Å Blomsterberg, Project presentation in Hydra, Greece, 2003 |
| 8e | Dissemin-ation report | - As described above (8a, 8b, 8c, 8d) and chapter 5.1 |

# Annex 1 Performance specifications

## *Overall performance specifications*

Energy use

Use of electricity for ventilation < 1 $kW/m^3/s$
Use of district heating < 90 $kW/m^2$/year
Total use of electricity < 25 $kW/m^2$/year

## *Performance specifications for rooms*

The performance specifications below are valid within the occupied zone for every room.

| Room | Area | Description | Performance specification | Comments |
|---|---|---|---|---|
| **101 + 106: shop + entrance** | 82 $m^2$ + 54 $m^2$ | Shop: Sale of books, handicraft etc. Central location close to entrance. | Light: daylight, should be possible to shade against direct sun light.<br>Lighting: > 150-500 lux, < 13 $W/m^2$ electricity<br>Ventilation: 0,35 $l/sm^2$, 7 l/sperson, air change efficiency > 40 %<br>Thermal comfort: operative temperature 18 – 22 °C (26 °C during summer)<br>Relative humidity: 35 – 60 %<br>Sound: from HVAC $L_{Aeq}$< 35 dB, $L_{Amax}$ < 35 dB, $L_{Ceq}$ < 50 dB; outside noise $L_{Aeq}$< 30 dB; airborne sound insulation to other rooms >48 dB (>40 dB for walls with door) | The performance specifications are valid during opening hours. |
| **112 + 114: Exhibition rooms** | 52 $m^2$ ,37 $m^2$ and 250 $m^2$ | Area for exhibition of work of art of varying character. Can be sculptures or installations as well as paintings. Shown will be exhibitions, which are experimental, new and unexpected.<br>A system for screening and mounting is needed | Alt. 1 with demanding exhibits<br>Light: adjustable 50-500[1] lux and vertical surfaces > 50 – 250 lux. Daylight, should be possible to shade against direct sun light, UV < 10 mikroW/lumen<br>Lighting (artificial): < 13 $W/m^2$ electricity, colour reproduction index (Ra-index) > 90, luminance distribution work of art : nearest surroundings : surrounding areas 5 : 3 : 1<br>Ventilation: 0,35 $l/sm^2$, 7 l/sperson, air change efficiency > 40 %<br>Thermal comfort: operative temperature 18 – 22 °C, air velocity < 0,15 m/s<br>Relative humidity: 45 – 60 %, max 5 % variation/day<br>Sound: from HVAC $L_{Aeq}$< 35 dB, $L_{Amax}$ < 35 dB, $L_{Ceq}$ < 50 dB; from outside $L_{Aeq}$< 30 dB; airborne sound insulation to other rooms >48 dB (>40 dB for walls with door), reverberation time < 1.5 s<br>Miscellaneous: possibility to bring in large works of art<br>Alt 2. with non-demanding exhibits<br>Light: adjustable 50-500[1] lux and vertical surfaces > 50 – 250 lux. Daylight, should be possible to shade against direct sun | Performance specifications are valid during opening hours, apart from the requirements on light, temperature, and RH, which are always applicable. |

| | | | | |
|---|---|---|---|---|
| | | | light, UV no limit<br>Lighting (artificial): < 13 W/m$^2$ electricity, colour reproduction index (Ra-index) > 90, luminance distribution work of art : nearest surroundings : surrounding areas 5 : 3 : 1<br>Ventilation: 0,35 l/sm$^2$, 7 l/sperson, air change efficiency > 40 %<br>Thermal comfort: operative temperature 18 – 24 °C (26 °C during summer), air velocity < 0,15 m/s<br>Relative humidity: 30 – 70 %<br>Sound: from HVAC $L_{Aeq}$< 35 dB, $L_{Amax}$ < 35 dB, $L_{Ceq}$ < 50 dB; from outside $L_{Aeq}$< 30 dB; airborne sound insulation to other rooms >48 dB (>40 dB for walls with door), reverberation time < 1.5 s<br>Miscellaneous: possibility to bring in large works of art | |
| **122: café** | 64 m$^2$ | For 40 guests, access to outdoor serving | Light: daylight<br>Lighting: > 300-500 lux, < 13 W/m$^2$ electricity<br>Ventilation: 0,35 l/sm$^2$, 7 l/sperson, air change efficiency > 40 %<br>Thermal comfort: operative temperature 18 – 22 °C (26 °C during summer), air velocity < 0,15 m/s<br>Sound: from HVAC $L_{Aeq}$< 35 dB, $L_{Amax}$ < 35 dB, $L_{Ceq}$ < 50 dB; outside noise $L_{Aeq}$< 30 dB; airborne sound insulation to other rooms >48 dB (>40 dB for walls with door) | The performance specifications are applicable during opening hours. |
| **201A: office** | 55 m$^2$ | 5 separate work places in a landscaped office. Possibility for coffee break/to sit comfortably and read magazines | Lighting: > 300-500 lux, < 13 W/m$^2$ electricity, colour reproduction index (Ra-index) > 80, luminance distribution working material : nearest surrounding : surrounding areas 5 : 3 : 1<br>Internal gains from office equipment: < 15 W/m$^2$<br>Ventilation: 0,35 l/sm$^2$, 7 l/sperson, air change efficiency > 40 %<br>Thermal comfort: operative temperature 18 – 22 °C (26 °C during summer), air velocity < 0,15 m/s<br>Sound: from HVAC $L_{Aeq}$< 35 dB, $L_{Amax}$ < 35 dB, $L_{Ceq}$ < 50 dB; from outside $L_{Aeq}$< 30 dB; airborne sound insulation to other rooms >48 dB (>40 dB for walls with door) | The performance specifications are applicable during office hours. |
| **205: creative workshop** | 35 m$^2$ | Dedicated to children and youth for creating. Possibility to display the | Light: daylight<br>Lighting: > 300-500 lux, < 13 W/m$^2$ electricity, colour reproduction index (Ra-index) > 90, luminance distribution work of art : nearest surrounding : surrounding areas 5 : 3 : 1 | The performance specifications are applicable during opening hours. Assume 10 persons. |

| | | | | |
|---|---|---|---|---|
| | | results on walls/floor | Ventilation: 0,35 l/s$m^2$, 7 l/sperson, air change efficiency > 40 %<br>Thermal comfort: operative temperature 18 – 22 °C (26 °C during summer), air velocity < 0,15 m/s<br>Sound: from HVAC $L_{Aeq}$< 35 dB, $L_{Amax}$ < 35 dB, $L_{Ceq}$ < 50 dB; outside noise $L_{Aeq}$< 30 dB; airborne sound insultation to other rooms >48 dB (>40 dB for walls with doors) | |
| **206: reference library** | 65 $m^2$ | Library for intensive studies and/or shorter breaks. Access to PC for Internet search. Central location with possibility for screening | Light: daylight<br>Lighting: > 300-500 lux, < 13 W/$m^2$ electricity, colour reproduction index (Ra-index) > 80, luminance distribution working material : nearest surrounding : surrounding areas 5 : 3 : 1<br>Internal gains for office equipment: < 15 W/$m^2$<br>Ventilation: 0,35 l/s$m^2$, 7 l/sperson, air change efficiency > 40 %<br>Thermal comfort: operative temperature 18 – 22 °C (26 °C during summer), air velocity < 0,15 m/s<br>Sound: from HVAC $L_{Aeq}$< 35 dB, $L_{Amax}$ < 35 dB, $L_{Ceq}$ < 50 dB; outside noise $L_{Aeq}$< 30 dB; airborne sound insulation to other rooms >48 dB (>40 dB for walls with door) | The performance specifications are applicable during office hours. Assume 10 persons. |

[1]Material group 1: maximum 50 lux or maximum 50 000 luxhours/year (50 lux x 8 hours/day x 125 days/year). Many lender require incandescent lighting for this group of exhibits.
Material group 2: maximum 200 lux or maximum 480 000 luxhours/year (200 lux x 8 hours/day x 300 days/year). This means that the light has to be turned off during non–opening hours and as consequence, if daylight is used it must be possible shut out the daylight. Non of values may be exceeded. Other materials can be illuminated according to exhibition situation. (the risk of glare limits the number of lux)